

Notes and Comments

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RECORDING DEVICES ON FREE-RANGING MARINE ANIMALS: DOES MEASUREMENT AFFECT FORAGING PERFORMANCE?¹

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Observations of foraging patterns are essential to understanding the energetic ecology of marine animals. However, direct observations are not often feasible in the field because most foraging takes place below the sea surface or at great distances from land. Attachment of data-recording devices to animals can greatly facilitate the collection of meaningful data. Devices are being used to an increasing extent on marine mammals (Kooyman et al. 1976, Ray et al. 1978), birds (Kooyman et al. 1971, 1982, Adams and Brown 1983, Lishman and Croxall 1983, Wilson and Bain 1984*a, b*), reptiles (Stoneburner 1982), and fish (Voegeli and Piucock 1980, Priede 1983*a*). These devices may supply data upon recovery (e.g., Kooyman et al. 1971, 1982) or through telemetry to local receivers (e.g., Voegeli and Piucock 1980, Priede 1983*a, b*) or to orbiting satellites (Stoneburner 1982). The effects of instrument mass and harness attachment on land animals are considered to have the potential of affecting the outcomes of experiments and observations (Dumke and Pils 1973, Gilmer et al. 1974, Perry 1981, Perry et al. 1981). However, the effects of devices on marine animals, which live in a much more viscous medium than air, have not been evaluated. In this study we investigated the effects of attached instruments on the foraging activity of the African Penguin (*Spheniscus demersus*). We show that instrument size may adversely affect foraging behavior, but that data obtained using devices of varying sizes can be used to back-calculate true foraging parameters of free-swimming penguins without devices.

Data-recording devices are especially important in studies of free-swimming penguins because these birds are inconspicuous on the surface of the water and are not visible during their frequent traveling and foraging dives. Instruments have been constructed to record speed (Wilson and Bain 1984*b*), foraging range (Wilson and Bain 1984*b*, Wilson and Achleitner 1985), dive time (Trivelpiece et al., *in press*), dive frequency and depth (Kooyman et al. 1982, Wilson and Bain 1984*a*). Results show that African Penguins are capable of sustained speeds of at least 7.5 km/h (Nagy et al. 1984)

and that other penguin species forage at depths exceeding 200 m (Kooyman et al. 1982). Measurements of foraging distance have also been used to estimate the energy cost of swimming and to construct energy budgets (Nagy et al. 1984).

Devices may affect performance in two ways. The mere presence of a device may modify behavior. However, in our experience with penguins this does not appear to be important; after a short period of adjustment, African Penguins with devices continued their normal nesting activity and entered the sea to forage with frequencies similar to control birds (Wilson and Bain 1984*a, b*). Second, the mass or drag of a device may retard swimming speed, thus reducing dive depth, foraging range, and the number of prey encountered. Instrument mass in itself probably does not adversely influence foraging behavior because attached devices are usually <1% of body mass (Wilson and Bain 1984*a, b*) and are partially buoyed by water displacement. Furthermore, penguins can ingest meals weighing up to 26% of their body mass (Davies 1956). On the other hand, streamlining effects may have a greater influence on speed and energy expenditure during foraging because water is a relatively dense medium. Streamlined body shape and plumage with reduced drag in water reflect the importance of hydrodynamic constraints on penguins (Nachtigall and Bilo 1980).

To measure the effects of instrument size, we recorded the mean speed and time spent foraging in 31 African Penguins in the vicinity of Saldanha Bay (33°03' S, 17°58' E), South Africa, between July 1981 and July 1984. All birds were nesting on Marcus or Malgas islands and had chicks <6 d old. Nesting birds have more predictable foraging patterns than do nonbreeding birds and allow more predictable instrument recovery (Nagy et al. 1984). Birds were fitted with speed meters (Wilson and Bain 1984*b*) and attachment devices with cross-sectional areas between 2.3 and 10.1% of the frontal cross-sectional area of a swimming penguin (14 040 mm²). Meters were attached to the birds by harnesses (Wilson and Bain 1984*b*) or by hose clips (Lishman and Croxall 1983). Devices and harnesses had masses representing ≈0.6% of a typical 3-kg African Penguin.

The stomachs of five experimental birds fitted with the smallest devices were pumped upon return to land (Wilson 1984), and mean prey mass was compared with that of 45 free-swimming birds. There was no significant difference between the two groups (experimental: \bar{X} = 150 g, SD = 124 g, n = 45; control: \bar{X} = 271 g, SD = 80 g, n = 5; t = 2.1, P > .05) which suggests that the smallest meters had virtually no effect on foraging behavior. On the other hand, two penguins fitted with an electronic distance meter 14.6% of penguin

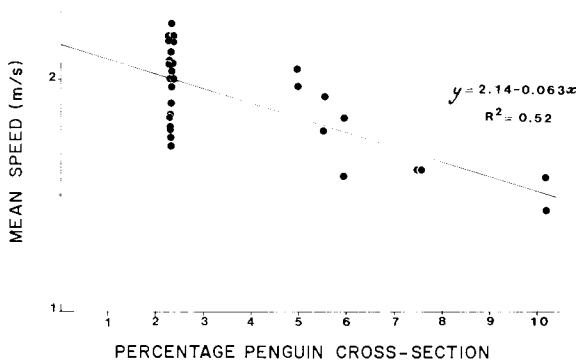


FIG. 1. Relationship between mean speed (y) during a typical foraging trip and percentage cross-sectional area (x) of an attached device relative to the frontal cross-sectional area of an African Penguin.

cross-sectional area (Wilson and Achleitner 1985) returned in emaciated condition after being absent for 8 and 10 d, respectively. These are unusually lengthy periods of foraging. During the study, 30 African Penguin nests were checked twice daily (0900 and 2100) to monitor parental attendance from the moment the first chick hatched until it was 5 d old. These observations showed that 142 (95%) foraging trips were < 1 d and 8 (5%) foraging trips were > 1 d but < 2 d.

Mean foraging time for the 31 birds carrying devices was 4.5 h. There was no significant difference between harness-fitted ($\bar{X} = 4.4$ h, $SD = 2.74$, $n = 10$) and hose-clip-fitted ($\bar{X} = 4.67$ h, $SD = 2.05$, $n = 21$) devices ($t = 0.31$, $P > .05$). However, mean speeds during foraging trips were inversely related to device size (percentage of penguin cross section) (Fig. 1). Penguins with the smallest devices averaged 2.0 m/s during a foraging period, but penguins with larger devices showed a linear decrease in mean speed. Birds with the largest devices had a mean speed one-fourth less than that of birds with the smallest devices. The traveling speed, y , (m/s) is related to device cross-sectional area as a percentage of penguin cross-sectional area, x , by the equation: $y = 2.14 - 0.063x$. About 50% of the variability in mean speed was explained by device size ($r^2 = 0.52$, $F_{1,29} = 30.95$, $P < .0005$).

Although these results show that the devices have an adverse effect on foraging, the regression allows us to predict foraging performance and energy requirements for free-swimming birds without devices. If African Penguins forage 4.5 h/d regardless of device size, birds carrying devices 0, 2.3, and 10% in cross-sectional area will travel 34.7, 32.3, and 24.5 km, respectively, at speeds reported here. The mass (g) of prey in penguin stomachs, y , measured on return to the nest is proportional to distance traveled in kilo-

metres, x , according to the equation: $y = 8.2x + 122$ (Wilson 1985a). However, because digestion commences soon after feeding, this does not represent the total amount of food available to the penguin and its chicks. Duffy et al. (1985) reported that the percentage of meal mass defecated is proportional to the amount of time after feeding, which for the African Penguin occurs at midday (Wilson 1985b). Using the digestion rates, the return times of individual birds and the amount of food brought back to the nest, the total mass of food ingested, y_T , is related to the distance traveled, x , by the equation: $y_T = 14.3x + 11$ ($r^2 = 0.72$, Fig. 2). Therefore the total amount of food ingested by birds carrying devices 10 and 0% of their cross-sectional areas would be ≈ 361 g and 507 g. Since African Penguins in the Saldanha Bay region feed almost exclusively on anchovies *Engraulis japonicus (capensis)* (Wilson 1985c), which have a metabolizable-energy content of 5.13 kJ/g (Nagy et al. 1984), the energetic content of these meals would be 1852 and 2601 kJ.

African Penguins with devices do not use significantly more energy per foraging trip than do free-swimming penguins (mean CO_2 productions of $1.027 \text{ mL} \cdot \text{g}^{-1} \cdot \text{h}^{-1}$, $SD = 0.147$, $n = 5$, and $0.992 \text{ mL} \cdot \text{g}^{-1} \cdot \text{h}^{-1}$, $SD = 0.069$, $n = 8$, respectively, $t = 0.59$, $P > .05$ [data from Nagy et al. 1984]). If we assume that free-swimming penguins and penguins with devices spend a total of 4.5 h swimming per day, and that they expend 212 kJ/h (Nagy et al. 1984), a total of 954 kJ is consumed in swimming. When this energy expenditure is added to the maintenance cost of $1137 \text{ kJ} \cdot \text{bird}^{-1} \cdot \text{d}^{-1}$ (Nagy et al. 1984), the total energy expenditure is $2091 \text{ kJ} \cdot \text{bird}^{-1} \cdot \text{d}^{-1}$. The surplus energy available to chicks from free-swimming penguins would be 510 kJ or 99 g of anchovy per day. African Penguin chicks between 2 and 5 d old require ≈ 50 g of anchovy per day (Cooper

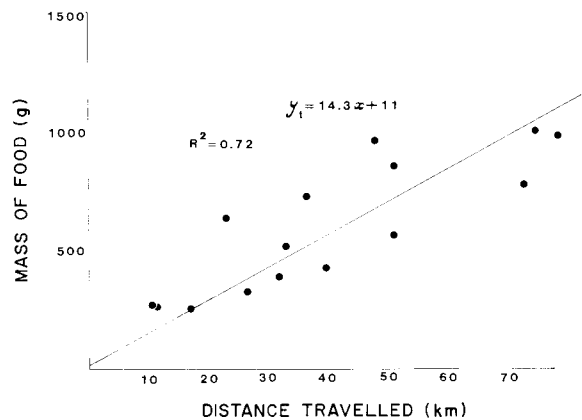


FIG. 2. Relationship between the total mass of food ingested and distance traveled by African Penguins.

1977). Therefore, free-swimming adults with two chicks catch enough anchovy for themselves and their chicks. Penguins carrying devices 10% in cross-sectional area have a deficit of 239 kJ (47 g of anchovy) in their own energy needs, and would have no anchovy available to feed their chicks. Devices up to a maximum of 6.8% in cross-sectional area could be put on nonbreeding adult penguins, following the same foraging pattern as a breeding bird, and the penguins could still balance their energy budgets.

Our results demonstrate that the attachment of recording devices to seabirds may adversely affect the outcome of experiments designed to study their foraging behavior and reproductive energetics. Although devices should have as little mass as possible, it appears more important for marine animals that their streamlining be altered as little as possible; device volume, size, and cross-sectional areas should be minimized. Although direct comparisons with free-swimming animals are difficult, indirect tests, such as dietary intake, may be used to assess the effects of the devices. In many cases, the results from the devices themselves may provide a calibration that can be used to correct for the biases introduced by their presence on the animals. Such corrections are critical to understanding the ecology of marine animals because even small differences in field observations may lead to unrealistic estimates of dietary intake and energy expenditure.

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